Modeling the polarization of Venus

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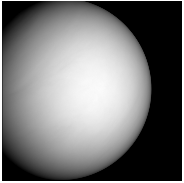
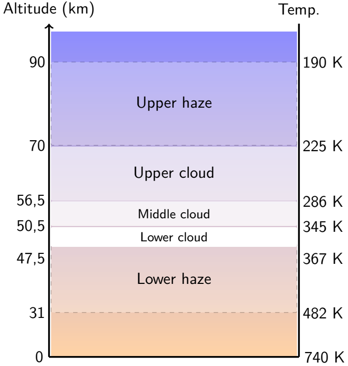
Venus clouds

Venus is enshrouded by thick clouds of sulfuric acid.

- Upper cloud layer composed of $r \simeq 1\ \mu\mathrm{m}$ particles ;
- haze layers made of $r \simeq 0.25\ \mu\mathrm{m}$ particles.



Venus in visible light (Messenger)



Structure of Venus' clouds (Loïc Rossi, CC-BY-SA)

Polarimetry on Venus

Polarimetry has been of a great importance in the characterization of Venus' clouds :

- Numerous ground-based observations as soon as 1922 [Lyot, 1929] ;
- Observations up to 1970s, analyzed by [Hansen and Hovenier, 1974] : identification of sulfuric acid ;
- Haze characterization with OCPP (*Pioneer Venus*) [Kawabata et al., 1980, Sato et al., 1996].

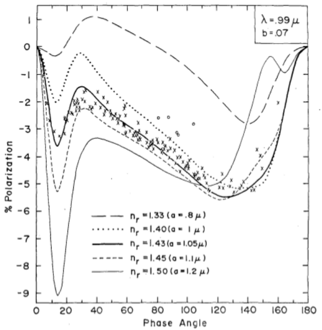
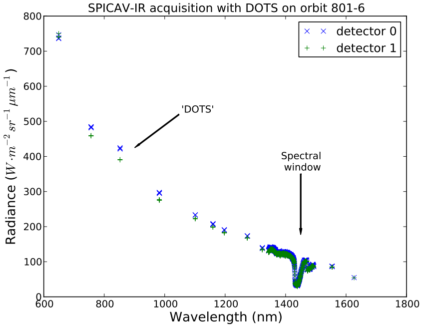


Figure from [Hansen and Hovenier, 1974]



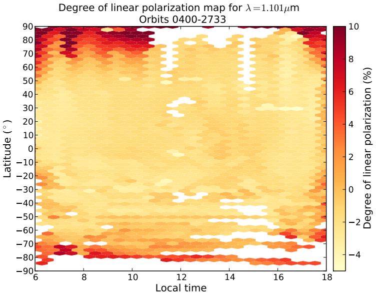
SPICAV-IR was a spectrometer onboard Venus Express

- working in the $0.65 - 1.7$ µm range ;
- 2° FOV ;
- up to 14 DOTS available ;
- based on an AOTF : measures I and Q ;

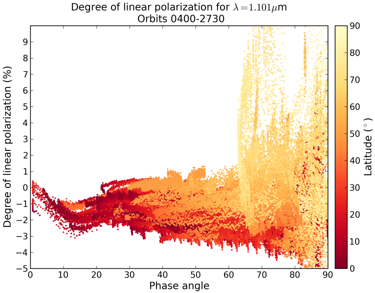
Degree of linear polarization

$$P_\ell = \frac{d_1 - d_0}{d_1 + d_0} = \frac{I_\perp - I_{//}}{I_\perp + I_{//}}$$

Polarimetric data

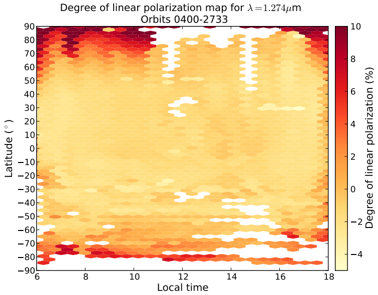


Polarimetric map at 1101 nm

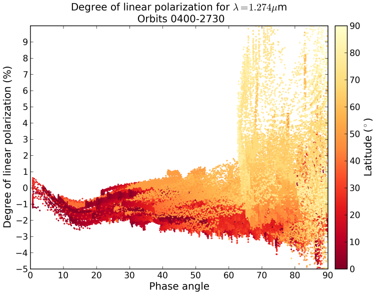


Polarisation as a function of phase angle and latitude.

Polarimetric data



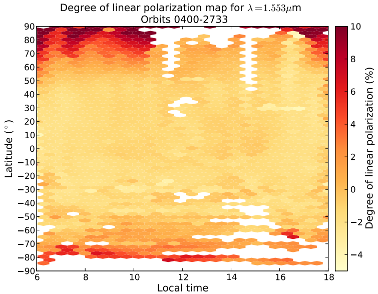
Polarimetric map at 1274 nm



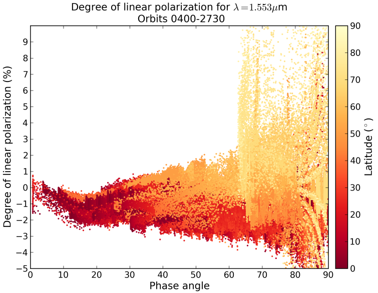
Polarisation as a function of phase angle and latitude.

Observations

Polarimetric data



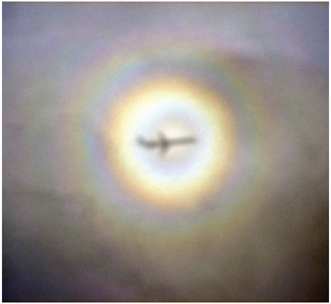
Polarimetric map at 1553 nm



Polarisation as a function of phase angle and latitude.

The glory

The glory is a back-scattering phenomenon visible on clouds or fog.



A glory on Earth. *Anders Sandberg (CC-BY)*

- Produced by sphericals scatterers only ;
- refractive index and radius dependent ;
- also used on Earth to characterise clouds [Bréon and Goloub, 1998, Mayer et al., 2004] ;

The glory

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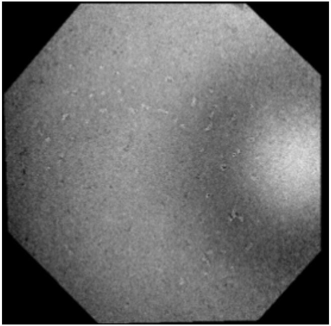


A glory observed on Venus by VMC

- Produced by sphericals scatterers only ;
- refractive index and radius dependent ;
- also used on Earth to characterise clouds [Bréon and Goloub, 1998, Mayer et al., 2004] ;
- also observed by VMC [Markiewicz et al., 2014].

Cloud model

Venus atmosphere modelled with infinite plane-parallel layers.

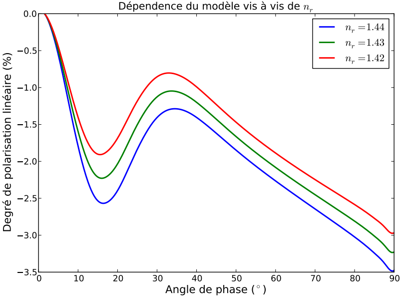
- Two layers containing haze or cloud particles ;
- simple scattering computed with Mie theory [de Rooij and van der Stap, 1984] ;
- multiple scattering computed with *Doubling-Adding* method [de Haan et al., 1987] ;
- scattering codes provided by Daphne Stam during STSM.

n_r, $r_{\text{eff}} \simeq 0.25$ µm,
$\nu_{\text{eff}} = 0.25$, τ_h

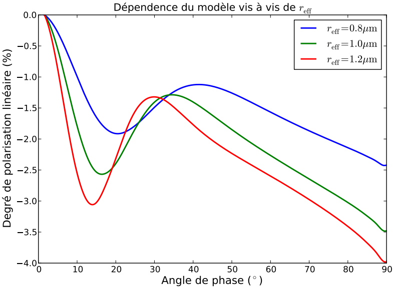
n_r, $r_{\text{eff}} \simeq 1$ µm,
$\nu_{\text{eff}} \simeq 0.07$, $\tau_c \simeq 30$

Modeling

Cloud parameters

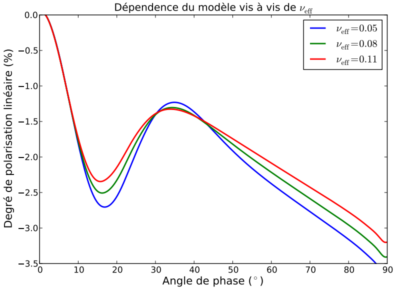


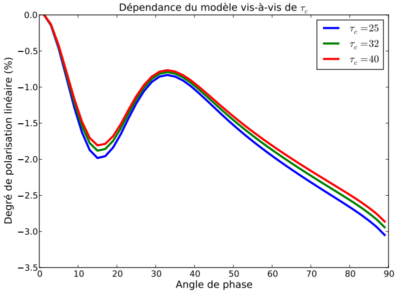
Model dependence on n_r in the clouds. Cloud with $\tau_c = 30$, $r_{\text{eff}} = 1$ µm, $\nu_{\text{eff}} = 0.07$. $\lambda = 1.101$ µm.



Model dependence with n_r in the cloud. Cloud layer with $\tau_c = 30$, $r_{\text{eff}} = 1$ µm, $\nu_{\text{eff}} = 0.07$ et $n_r = 1.42$. $\lambda = 1.101$ µm.

Cloud parameters

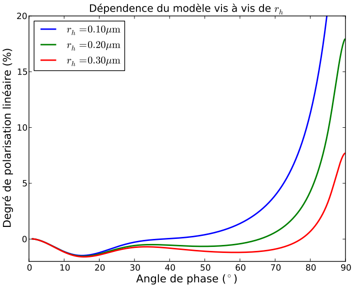




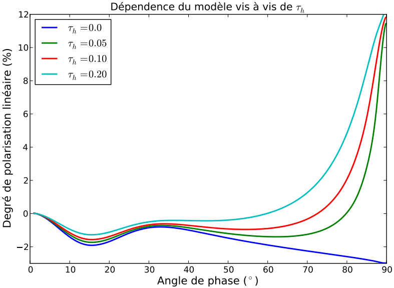
Model dependence on ν_{eff} in the clouds. Cloud layer with $\tau_c = 30$, $r_{\mathrm{eff}} = 1$ µm et $n_r = 1.42$. $\lambda = 1.101$ µm.

Model dependence with τ_c du nuage. Cloud layer with $r_{\mathrm{eff}} = 1$ µm, $\nu_{\mathrm{eff}} = 0.07$ et $n_r = 1.42$. $\lambda = 1.101$ µm.

Haze parameters



Model dependence with r_h in the haze. For the hazes, $\tau_h = 0.1$, $\nu_{\text{eff}} = 0.25$ et $n_r^h = 1.42$. $\lambda = 1.101$ µm.



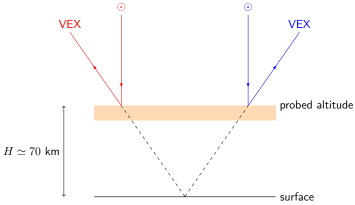
Model dependence with τ_h in the haze layer. For the hazes, $r_{\text{eff}} = 0.25$ µm, $\nu_{\text{eff}} = 0.25$ et $n_r^h = 1.42$. $\lambda = 1.101$ µm.

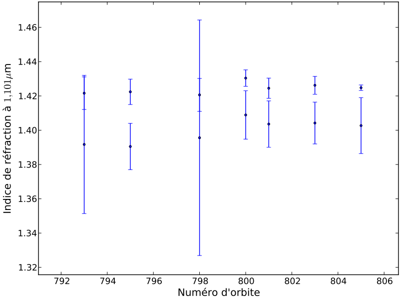
Procedure

- At low latitudes, glories are used to characterize the cloud layer ;
  - "double" glories are split between their two branches
- at higher latitudes, we can estimate the column density of the haze particles ;
  - assumptions are made on the properties of the cloud layer below
- six-wavelength characterisation ;

Results

Double glories

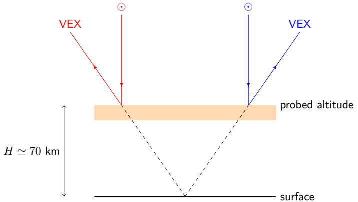


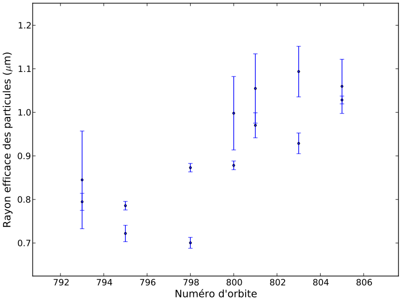


- Double glories show small scale variabilities of the clouds ;

Refractive indices at 1101 nm on some “double” glories.

Double glories





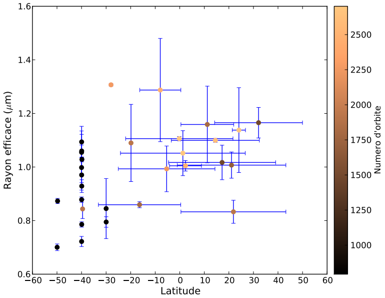
- Double glories show small scale variabilities of the clouds ;

Effective radii on some "double" glories.

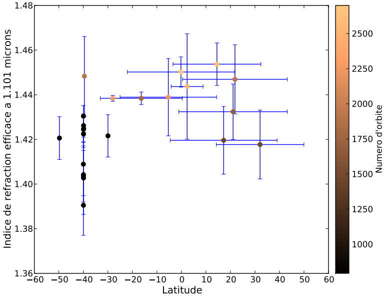
Results

Clouds spatial variability

Measurements conducted on glories show temporal and spatial variabilities.

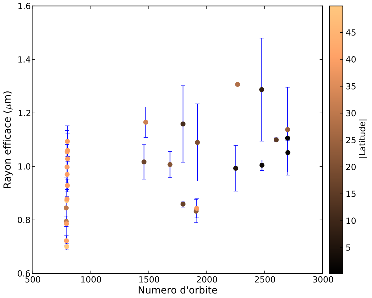


r_{eff} as a function of latitude. Only measures with $\sigma/r_{\text{eff}} < 15\%$ are shown.

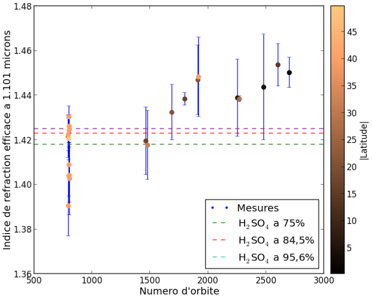


n_r at $1,101$ μm as function of latitude. Only values with $\sigma/n_r < 2\%$ are shown.

Clouds temporal variability



r_{eff} as a function of orbit number.



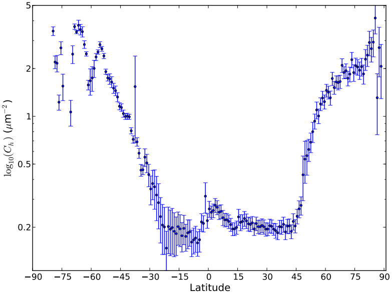
n_r at 1.101 µm as a function of orbit number.

Our measures are in agreement with other observers

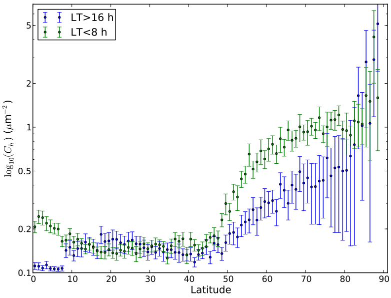
- r_{eff} latitudinal variation is also observed by VMC [Shalygina et al., 2014, Petrova et al., 2015b, Petrova et al., 2015a] and OCPP [Knibbe et al., 1997] ;
- n_r latitudinal variation also observed by VMC ;
- the secular variation of r_{eff} and n_r was not observed before.
- Average radius and refractive index increase with time :
  - a contaminant (S_x ?) is required to explain high values of n_r and would increase the radii ;
- UV albedo decreases during the mission [Lee et al., 2015], in correlation with SO_2 abundance [Marcq et al., 2013] ;
- **Gazeous sulfur would turn into solid and contaminate droplets of acid.**

Results

Haze column density

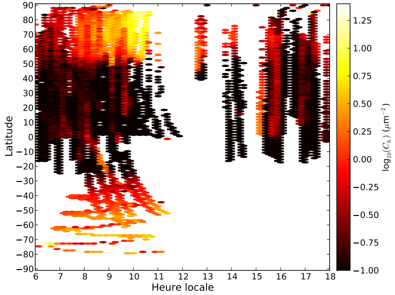


Haze column density as a function of latitude.

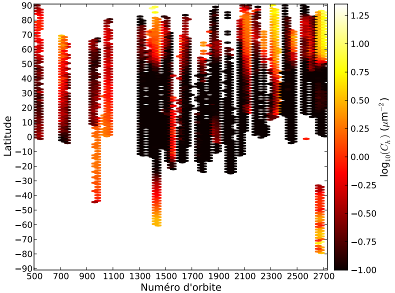


Latitudinal variations of C_h : morning/evening comparison.

Haze column density



Map of haze column density (in $\log$). Bins of 15 min by 2°.



$\log$ of column density as function of orbit number and latitude. Bins of 30 d by 2°.

Analysis

These results are in agreement with previous observations :

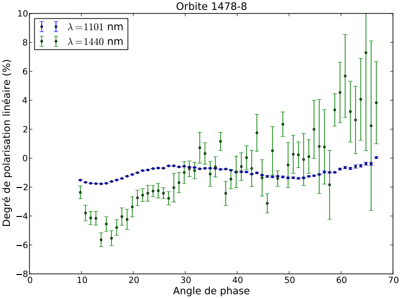
- [Kawabata et al., 1980, Sato et al., 1996] measured the optical thickness of the haze layer :
  - C_h varies from $0,23\ \mu m^{-2}$ near the equator and is higher than $3\ \mu m^{-2}$ beyond $50°$ of latitude ;
- [Knibbe et al., 1998, Braak et al., 2002] show a long-term decrease of C_h along the PVO mission ;
- Morning/evening difference also observed :
  - [Shalygina et al., 2014] also require more hazes in the morning with VMC.
  - But [Braak et al., 2002] see a symmetry around noon.

Conclusions

Polarisation dans les bandes d'absorption

SPICAV-IR also measures polarization in the CO_2 absorption band.

- More absorption means more scattering ;
- higher degree of polarization ;
- sensitivity to gaz pressure, even in the IR [Knibbe et al., 2000, Stam et al., 1999] ;
- a student (Nicolas Bott) worked on this.



Polarisation difference DOTS/bande

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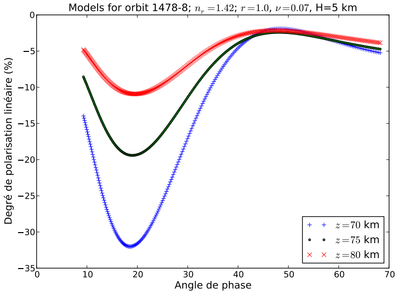

Effect of z_{top}

Polarisation dans les bandes d'absorption

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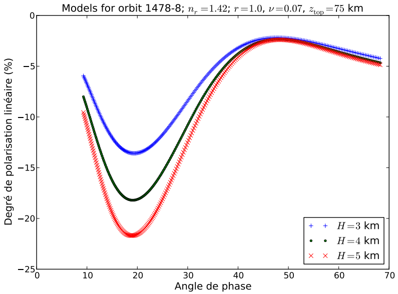

Effect of H

Summary

- Properties of the clouds and hazes are retrieved by polarimetry :
  - Refractive indices and radii vary with latitude and during the mission
- Variability of the haze column density was measured :
  - C_h increases with increasing latitude
- Possible study of vertical distribution and cloud-top altitude with polarization in absorption band ;
- Moving to TU Delft in October.

Acknowledgements :

- le COST MP1104 « Polarimetry as a tool to study the Solar System and beyond » ;
- the LabEx ESEP, the state and the ANR in the « investissements d'avenir » programme via the « initiative d'excellence » PSL*

Conclusions

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Expansion of Mie scattering matrices in generalized spherical